GENERAL MOTORS CORPORATION
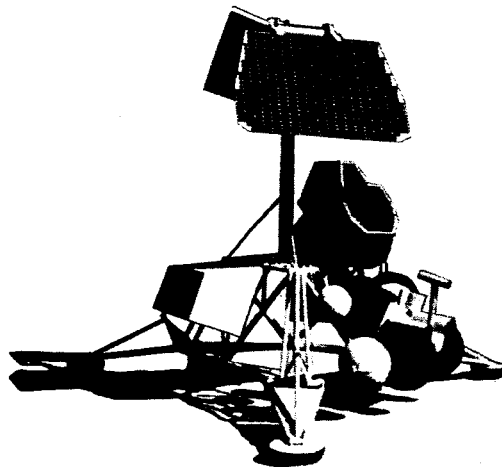
Final Report

SURVEYOR LUNAR ROVING VEHICLE

Phase I — JPL Contract 950657

Work NAS 7-100

VOL. II: APPENDIXES

Section V Additional Information on RTE

GM DEFENSE RESEARCH LABORATORIES   SANTA BARBARA, CALIFORNIA

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PREFACE

This report is one of a series of reports prepared under
JPL Contract No. 950657 by GM Defense Research Labora-
tories, Santa Barbara, California, and its major subcon-
tractor for electronics, Radio Corporation of America,
Astro-Electronics Division, Princeton, New Jersey.

SECTION V

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ADDITIONAL INFORMATION

V. 1   ADDITIONAL COMMENTS ON RTE

V. 1-1 Introduction

The following information was received after the submission deadline of the Final Report. This information modifies Section II, Electronic Subsystems, Appendix III, Power Supply Subsystem by eliminating Tables II. 3-16 through II. 3-19 and adding the following information. General reference is made to the Power Supply Subsystem Appendix throughout this section.

V. 1-2 **Recent RTE Information from Martin-Marietta Corp.**

The recent information received from the Martin-Marietta Corp. changes the RTE weights. The new weights are tabulated in Tables 1 and 2 for lead telluride and silicon-germanium thermocouple types, respectively. The data is also shown graphically in Figures 1 and 2. The requirements set forth for the RTE were the same as those indicated before, but are repeated for convenience:

Fuel : Cm_{242} or Po_{210}

Mission Life = 100 to 110 days

Power output vs time : Constant, at the levels given in Tables 1 and 2

PbTe couples

Hot junction temperature = 1000° F

Heat rejection temperature = 350° F

Si-Ge couples

Hot junction temperature = 1500° F

Heat rejection temperature = 500° F

For this purpose lunar impact is defined to occur at a velocity of approximately 7000 ft/sec. (This is the velocity that would be developed if the retro-rocket failed to perform.)

V. 1-3 **Recent RTE Information from General-Atomics, Inc.**

The recent information from General Atomics for a 30-watt output RTE is summarized in Table 3.

The requirements set forth for the RTE were as follows:

Fuel : Cm_{242}

Mission Life = 180 days

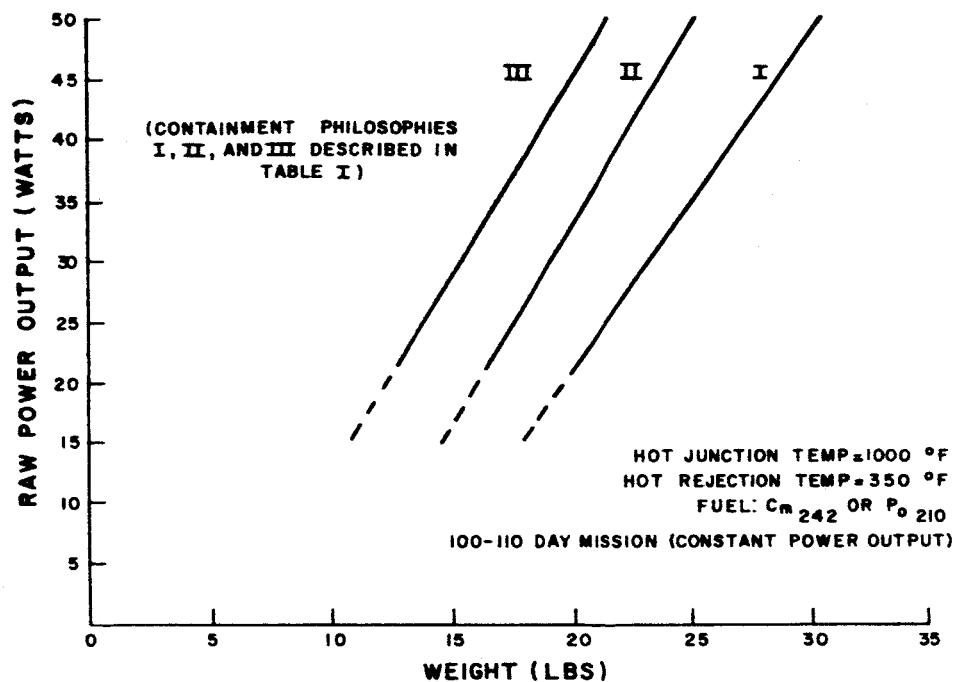Power output vs. time : Constant (Hot junction temperature controlled by heat-dump door)

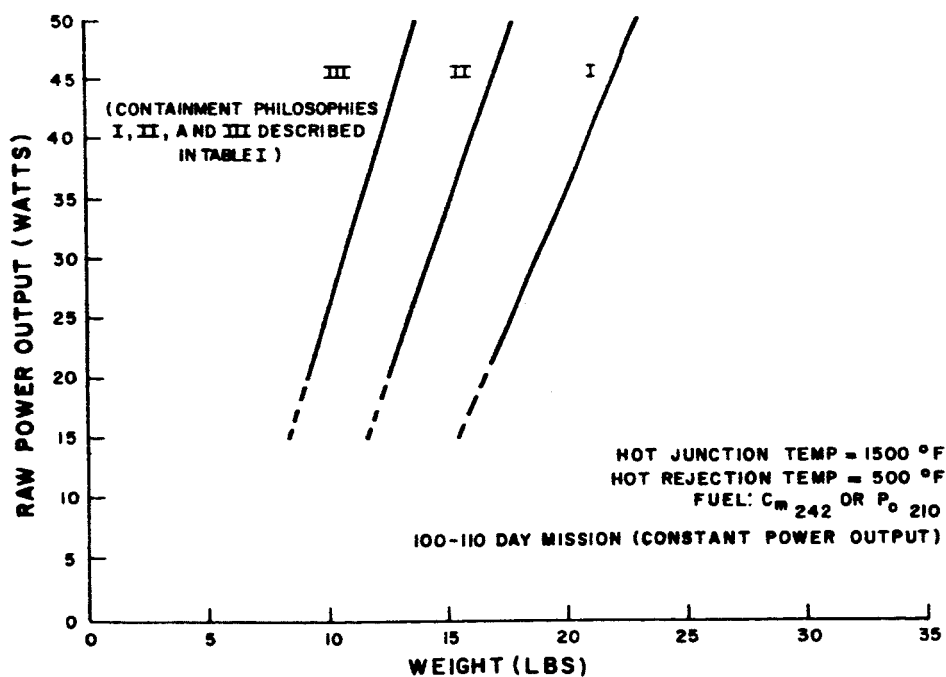**Figure 1.   RTE Raw Power vs Weight : Pb Te Thermoelements**

Figure 2.   RTE Raw Power vs Weight : Si-Ge Thermoelements

TABLE 1

LEAD TELLURIDE CONVERSION ELEMENTS

Raw Power Output (watts)	Container Weight (lbs) *Containment Philosophy		
	I	II	III
20	19.9	16.2	12.5
35	25.2	20.8	17.0
50	30.5	25.5	21.5

*Containment Philosophy

  I – Earth re-entry fuel containment and lunar impact fuel containment

  II – Earth re-entry fuel containment and no lunar impact fuel containment

  III – Earth re-entry fuel burn-up and no lunar impact fuel containment

TABLE 2

SILICON-GERMANIUM CONVERSION ELEMENTS

Raw Power Output (watts)	Container Weight (lbs) *Containment Philosophy		
	I	II	III
20	16.5	12.5	9.1
35	19.7	15.1	11.3
50	23.0	17.7	13.7

*Containment Philosophy: Same as defined in Table 1.

TABLE 3

*CHARACTERISTICS OF GENERAL-ATOMICS, INC. RTE

Hot Junction Temp (°C)	400	500	400	500
Cold Junction Temp (°C)	275	275	200	200
Conversion Elements	PbTe	Si–Ge	PbTe	Si–Ge
Container Dimensions, (each side of cube, ft)	0.98	0.98	1.12	1.21
Container Weight (lbs)	6.0	6.0	6.5	7.0
Specific Power (watts/lb)	5.0	5.0	4.6	4.3
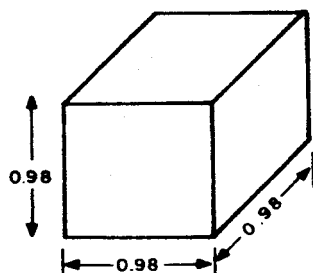
Container Dimensions

*Containment Philosophy III (only):

Earth re-entry fuel burn-up and no lunar impact fuel containment. (This philosophy is the one presently accepted by the Martin-Marietta Corp. The final philosophy must, of course, ultimately be defined by the Atomic Energy Commission.

PbTe and Si-Ge couples

Hot junction temperature = As specified in Table 3

Cold junction temperature = As specified in Table 3

Containment Philosophy –

III only: Earth re-entry fuel burn-up and no lunar impact fuel containment

The last two columns in Table 3 show the effect of reducing the cold-junction temperature; by this reduction the over-all efficiency of the generator increases with a resulting decrease in fuel requirements, but at the expense of both weight and volume.

Table 3 indicates that there is no particular advantage to be gained by using Si-Ge instead of PbTe thermocouples. It is true, however, that the hot junction temperature for Si-Ge was limited to 500°C; if this limitation was removed, Si-Ge would be shown to be superior on an over-all system weight basis.

V. 1-4 RTE Comparison

A comparison of the specific power quoted by General-Atomics, Inc. and the Martin-Marietta Corp., for containment philosophy III and a 30-watt output, shows a rather large discrepancy. (Containment philosophy III and a 30-watt output were used as the basis for comparison because General-Atomics, Inc. data was supplied for this basis only.) This comparison is summarized in Table 4 In view of the experience of the Martin-Marietta Corp. in developing and building RTE flight hardware, their data is considered more realistic. However, during Phase II of the SLRV Program, the discrepancies in the data will be further explored.

V. 2 PRELIMINARY SUBSYSTEM DESIGN OF AN RTE-BATTERY POWER SUPPLY SUBSYSTEM

V. 2-1 Introduction

A preliminary design for an RTE power supply subsystem has been generated, based only on operate time (duty cycle) and RTE specific power output, since the RTE is a "government-furnished-equipment" item. The latter parameter has been used in view of the state-of-the-art status of the RTE.

TABLE 4

*COMPARISON OF RTE CHARACTERISTICS

	Martin-Marietta Corp.		General-Atomics, Inc.	
	PbTe	Si-Ge	PbTe	Si-Ge
Power Level (watts)	30	30	30	30
Mission Life (days)	110	110	180	180
Hot Junction Temp (°C)	535	840	400	500
Cold Junction Temp (°C)	---	---	275	275
Radiator Temp (°C)	175	260	---	---
Specific Power (watts/lb)	1.9	2.8	5.0	5.0

*For Containment Philosophy III and a 30-watt output

This design is based upon a low-level voltage output on the order of 4 to 6 volts (corresponding to the power output of interest). This type of RTE generator has been space qualified and is presently used in some satellites.

The block diagram of the suggested design is shown in Figure 3   It requires RTE outputs within the range of 17.5 to 43 watts, for operate-duty cycles of from 6 to 24 hours per earth day, respectively. To achieve minimum weight and maximum efficiency, the battery has been placed to power the unregulated bus loads directly; thus, all other loads, except those required at the battery voltage level, must be supplied by the RTE alone. This condition places a usable lower limit (17.5 watts) on the RTE output with the system of Figure 3   Operate time duty cycle capability is shown in Figure 4.

Specific RTE weight information is not available at this time. Figure 6 can be an assist in estimating the over-all power supply subsystem weight. Once the RTE watts-per-pound is obtained, the over-all weight can be determined. Paragraph V.2-4 (Preliminary Weight Summary) includes weight comparisons between the RTE and the solar array power subsystems.

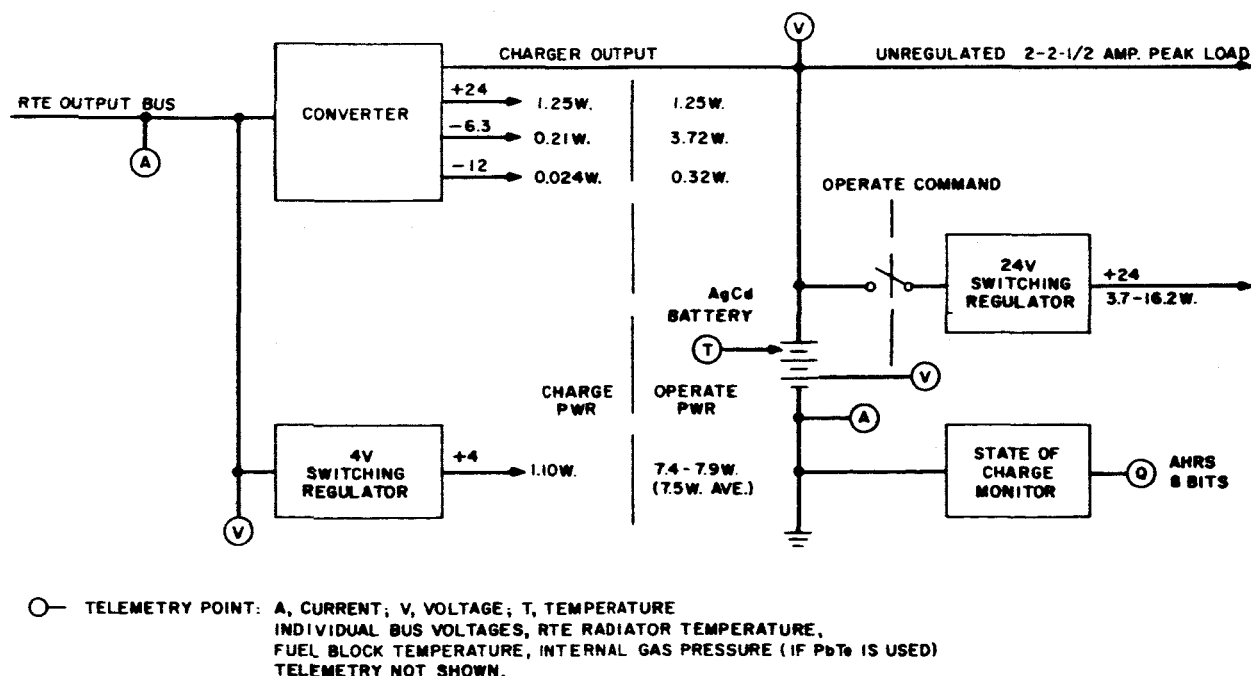
O— TELEMETRY POINT: A, CURRENT; V, VOLTAGE; T, TEMPERATURE
INDIVIDUAL BUS VOLTAGES, RTE RADIATOR TEMPERATURE,
FUEL BLOCK TEMPERATURE, INTERNAL GAS PRESSURE (IF PbTe IS USED)
TELEMETRY NOT SHOWN.

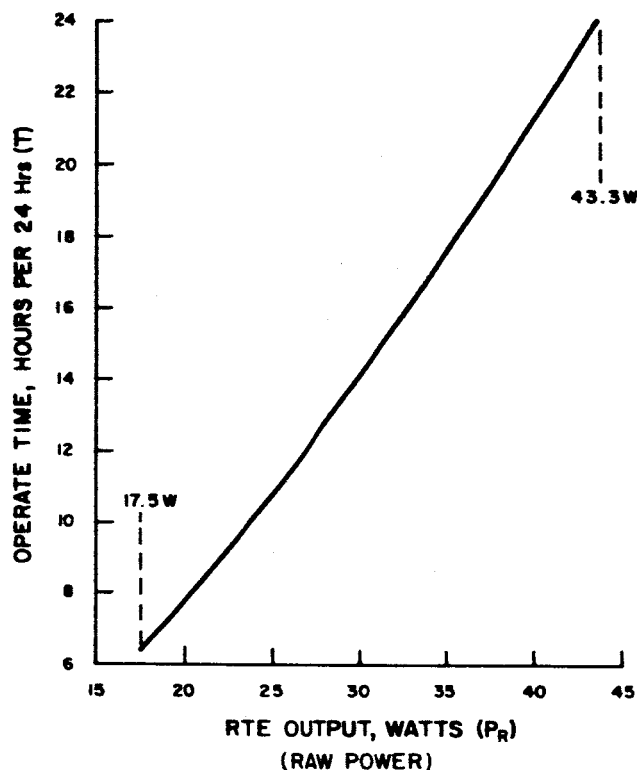Figure 3.   Power Supply Subsystem Block Diagram

Figure 4.   Variation of Operate Duty Cycle with Amount of Fixed RTE
Output Power for Power Supply Subsystem of Figure 3

V. 2-2 Power Subsystem Description and Operation

Two types of voltage regulators are used: switching regulators and a multi-tap voltage converter.

A switching regulator is the most efficient voltage regulator type, provided no great amount of up or down conversion is required. To supply the +4-volt regulated bus, advantage is being taken of the fact that, within the power range of interest, the RTE in this system is essentially a low-voltage source within the probable range of 4 to 8 volts. A transformerless switching regulator is used to convert one low voltage to another in this case, assuring a relatively high conversion efficiency at the +4-volt output.

For similar reasons, another switching regulator is used to supply the +24-volt power during the Operate mode.

A regulated converter is used to supply (1) all −12 and −6.3-volt regulated power, (2) the +24-volt bus required continuously (during both the Charge and Operate mode), and (3) the battery charge power from the charger output. The charger output is not voltage regulated; it is at a voltage level determined by the battery. However, it may be current-limited to a current value determined by the RTE capability and desired

Operate duty cycle, to protect both the converter electronics and the battery. To minimize battery size and the required load carrying capability of the regulatory electronics, the battery voltage selected is such that the unregulated bus loads can be supplied directly.

Condition of end-of-charge can be handled and acted upon in one of at least two different methods. The first method uses the state-of-charge monitor, as in the solar array subsystem design. In this case, a condition of full charge is said to be reached when all amp-hours discharge is replenished, plus a small percent overcharge. At this time, the mode is changed from Charge to Operate. In the second method, a temperature-compensated voltage cutoff can be used to sense the end-of-charge voltage and to decrease the charge current gradually (in conjunction with the state-of-charge monitor). Final selection of the charge mechanism will depend upon the relative charge rate, RTE capability, and the desired Operate time duty cycle.

The configuration of Figure 3 is analyzed in paragraph V.2-5. Loads at all points except at the battery voltage level are considered fixed in a particular operating mode (Charge or Operate); a relatively insignificant exception to this is the +4-volt bus output in Operate. At battery voltage, however, the load is variable. For that reason, the battery, unregulated bus, and the +24-volt switching regulator, are considered as a separate system in the analysis. This system is powered by the charger output less a fixed telemetry loss. Since the amount of charger output is relevant to the desired Operate time duty cycle, it is integrated into an over-all expression for the required RTE output as a function of the operate time. The plot appears in Figure 4.

In the block diagram of Figure 3, power levels at most of the load buses include additional small amounts of power required for bus voltage telemetry and the state-of-charge monitor.

V. 2-3 Battery Requirements; Specific Per-Cycle Operate Time

The battery charge current and the required battery capacity (based on the 50 percent depth-of-discharge and the one-hour-minimum-per-cycle Operate-time criteria) have been determined in paragraph V. 2-5. Both are plotted in Figure 5. It is seen that as the operate-time duty cycle (and therefore the RTE output: P_R) is increased, less battery capacity is required and more battery charge current is available. Eventually a point is reached where the relative recharge rate exceeds one half of the total on-board battery capacity, or $C/2$ (tentatively accepted as the maximum charge rate). From that point on, another curve is drawn (short dashes) to indicate the variation the battery capacity would have to follow to just keep up with the criterion of $C/2$ maximum recharge as the charge current is increased. Thus the reason for the peculiar V-shaped variation of the required battery size with Operate-time duty cycle.

Until the battery size is charge limited (C/2), the per-cycle Operate time Δt is one hour -- by definition -- as the minimum acceptable time to operate at any one time. But as the battery is made larger to accomodate a greater charge, Δt can be greater than one hour without exceeding 50 percent depth of discharge. A plot of ΔT vs Operate-time duty cycle appears in Figure 5; from the point where the battery size is limited by charge, and on, value of ΔT is obtained by dividing amp-hours battery capacity (solid curve) by the capacity required to operate for one hour.

The battery that has been selected is a silver-cadmium type. The plot of battery weight (Figure 5) is an approximation derived from data published by Yardney Electric Corporation on silver-cadmium button cells. It is based on a 24-cell battery, although further investigation is required to determine the capability of such a battery to sustain minimum voltage under peak load conditions.

A study of the adaptability of nickel-cadmium batteries has been made. This type was rejected not only because of the almost certain weight increase, but also because the Ni-Cd batteries require more overcharge than the Ag-Cd batteries. More overcharge required means lowered duty cycles or greater RTE weight, or both, depending on desired goals. Charge rates in this system are relatively high, and may be as high as C/2. A more complex charge mechanism would be required to insure safe operation of Ni-Cd batteries under that condition, unless additional weight penalties are paid in terms of increased battery size. Finally, the Ni-Cd battery terminal voltage is more temperature-sensitive; temperature compensation of the charging mechanism would be required.

The Ni-Cd batteries have a longer cycle life. However, the design is based on the storage system reaching the 50 percent depth of discharge point no more than about one hundred times (during operation on the moon plus test cycles). This assumes a minimum per-cycle operate time of one hour and a total operate time of 100 hours for the SLRV mission. Available data shows the silver-cadmium batteries to be capable of considerably more than the required number of cycles.

V. 2-4 Partial Weight Summary

The power subsystem weight W is assumed to equal

$$W = W_e + W_B \ f \ (P_R) + \frac{P_R}{a} \qquad \text{pounds}$$

where W_e is electronics weight, including telemetry; this is estimated to be 2.5 pounds, with all components to be packaged in compartment No. 2. This weight is relatively independent of the RTE output and duty cycle.
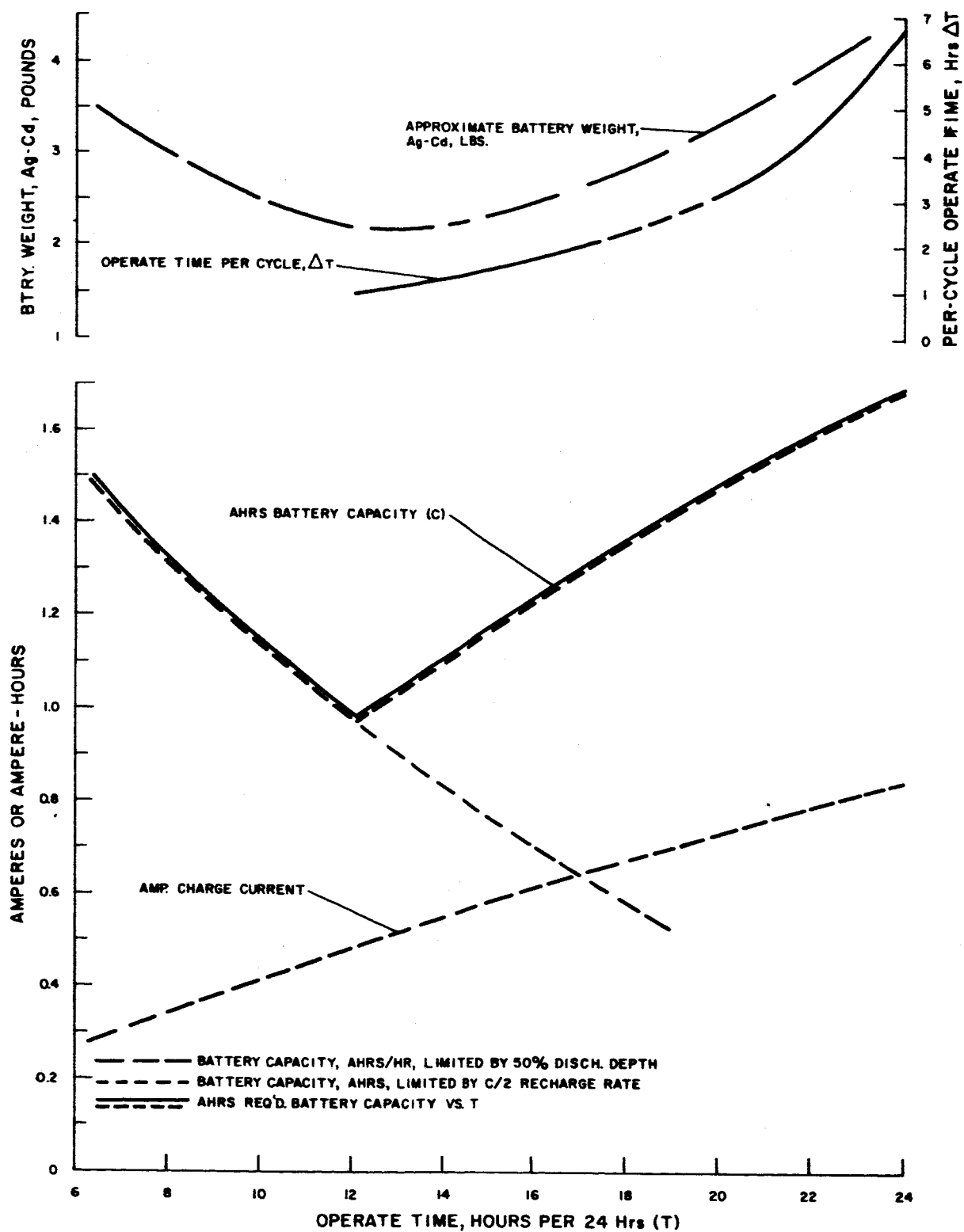
Figure 5.   Battery Requirements for the Power Supply Subsystem

W_B is the approximate battery weight, as in Figure 5.

P_R is watts RTE output.

a   is RTE watts per pound

Definite information regarding quantity "a" is not available at this time. Even though some specific data is available regarding RTE power density from various manufacturers, this data is known to vary widely with the range of power outputs, particular safety philosophy, thermocouple material, and a particular point in time in the future related to projected state-of-the-art. For that reason, Figure 6 has been prepared showing the total subsystem weight W over a wide range of possible specific power values.

The weight summary for the solar array power subsystem design shows 15.5 pounds for the total weight. In addition to that weight, an additional 1.5 pounds of structural support is chargeable to the solar array subsystem, for an effective total weight of 17 pounds. The solar array approach has been shown to be capable of 12.3 hours average operate time per earth day. Based on this information and that of Figure 6, the following generalizations can be made concerning the RTE subsystem weight:

(1)   To support 10 hours Operate per 24 hours and be equal in weight to the solar array system (17 pounds), a 24-watt, 2.0 watts per pound RTE is required.

(2)   To equal the solar array system both in weight and operate capability, a 27 to 28 watt, 2.3 watts per pound RTE must be available.

Other conclusions for various other duty cycles and weights can be drawn by referring to Figure 6.

V. 2-5 Technical Analysis

Load Profile at Battery Voltage

The battery voltage provides the unregulated bus voltage level and input to the +24-volt switching regulator. The switching regulator supplies all regulated power at +24 volts required in the Operate mode, with the exception of the command receiver power required in charge and supplied continuously by the +24-volt regulated converter output.

It has been shown and stated in the Final Report that, from the overall required energy viewpoint (required size of the RTE, in this case), the power profile when in the Smooth Moon mode is the worst case.
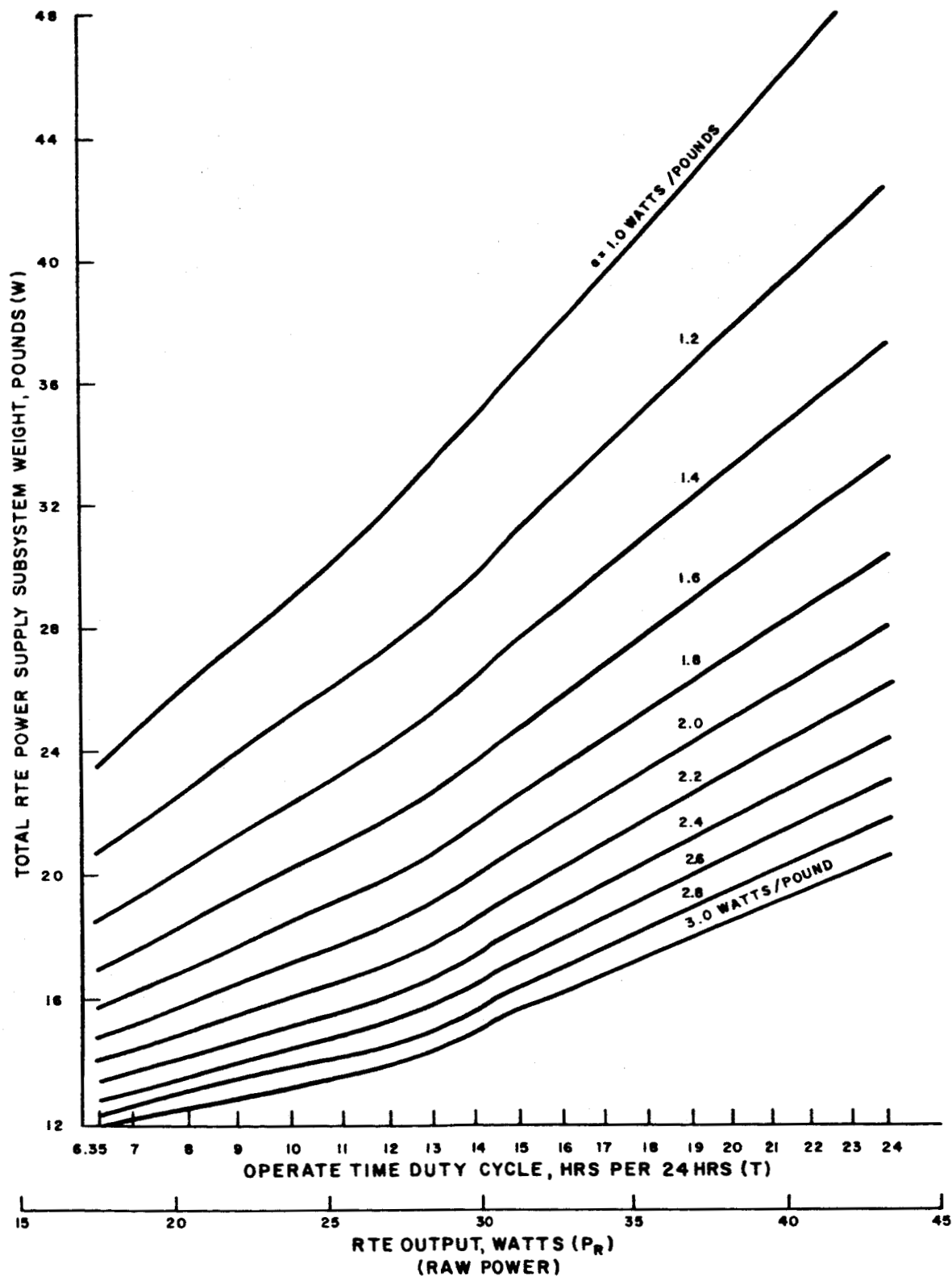
Figure 6. Total RTE Power Supply Subsystem Weight vs RTE Power Output and Duty Cycle, for Various RTE Power Densities (Converter Not Included)

that, from the overall required energy viewpoint (required size of the RTE, in this case), the power profile when in the Smooth Moon mode is the worst case.

Using the referenced technical material and the assumption that the average +24-volt switching regulator efficiency is 85 percent, smooth-moon power profiles at the battery unregulated bus can be calculated. Thus, at switching regulator input, the power profiles are as shown in Figures 7 and 8; the +24-volt (minimum) unregulated bus load profiles are as shown in Figures 9 and 10.
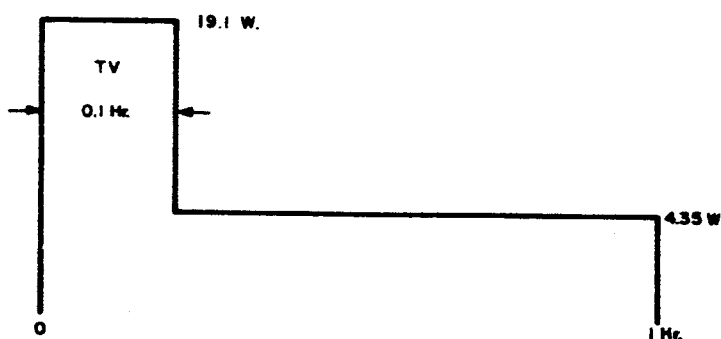
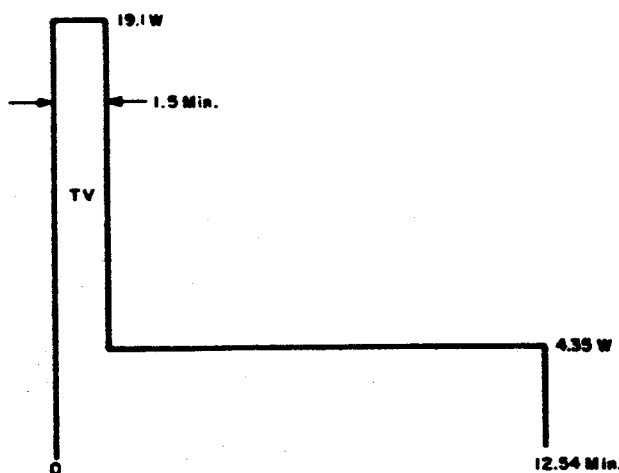Figure 7. Guidance Step, Smooth Moon, Regulator Input

Figure 8. Contour Mapping Step, Regulator Input
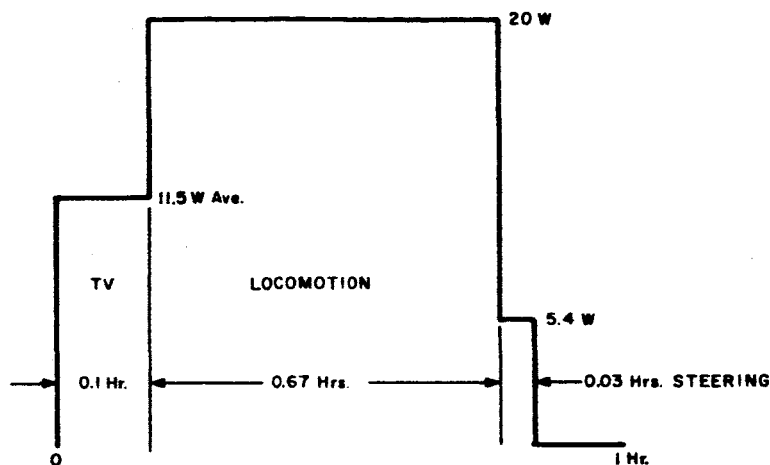
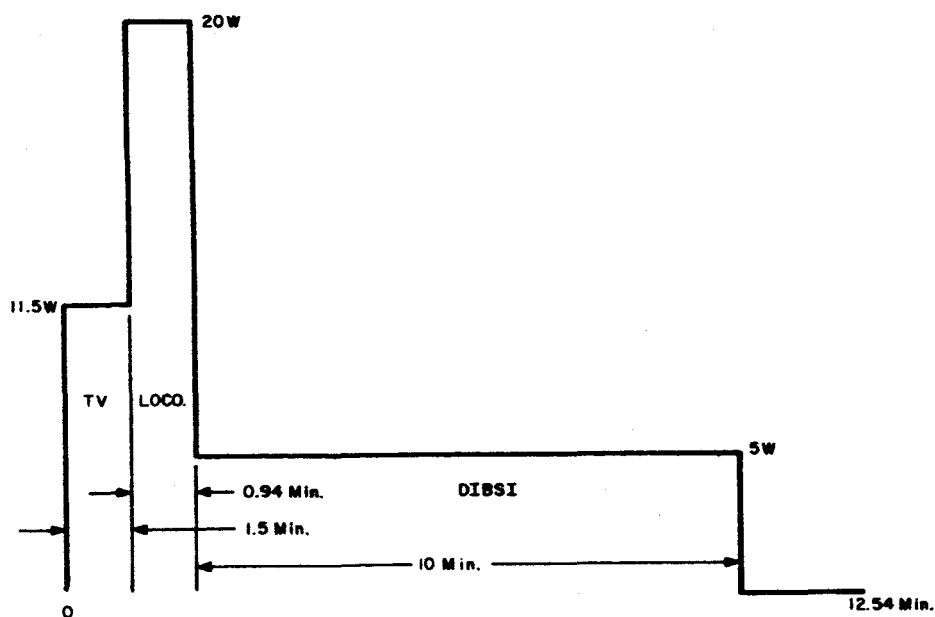Figure 9.   Guidance Step, Smooth Moon, Unregulated Loads

Figure 10.   Contour Mapping Step, Unregulated Loads

The over-all (integrated) power profile for the smooth moon case, at battery voltage level, is arrived at by adding loads of Figures 7   thru 10   in proper time sequence; it is shown in Figure 11.
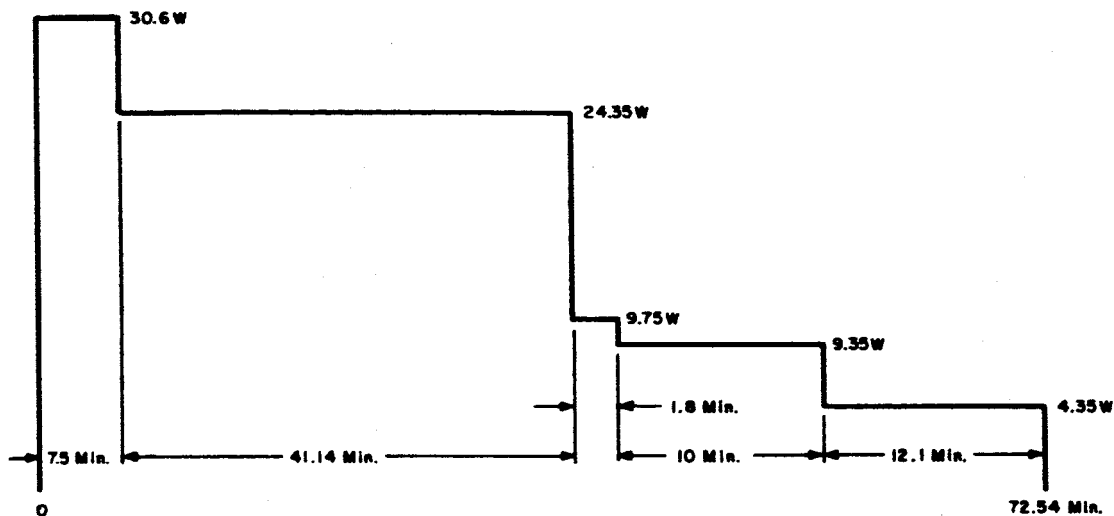
Figure 11. Integrated Power Profile at Battery Voltage Level when in
Smooth-Moon Mode

Charger Output Power Availability

Amount of power appearing at the charger output of the converter is the power difference between the RTE output and other load, regulator loss, and telemetry requirements. Loads at the +4-volt switching regulator output and the +24, -6.3, and -12-volt converter outputs will be satisfied first; any excess raw power available over and above that needed to supply these regulated buses will appear at the charger output.

During Charge:

$$\left(P_R - P_{TR}\right) = \frac{P_4'}{e_4'} + \frac{P_s'}{e_s} + \frac{P_r}{e_r} + \frac{P_c'}{e_c} \qquad (1)$$

Substituting numerical values and solving for P_c',

$$P_c' = \frac{P_R - 0.6}{1.25} - 2.84 \ watts \qquad (2)$$

P_c' is the total charger output during Charge. Amount of power available for charging the battery is that less the required telemetry circuitry loss P_{TB}:

$$P_B = P_c' - P_{TB} \tag{3}$$

Substituting equation (2) into (3),

$$P_B = \frac{P_R - 0.6}{1.25} - 3.44 \text{ watts} \tag{4}$$

By setting $P_B = 0$, P_R is found to equal 4.9 watts, which is the minimum RTE power required before charge can begin.

During Operate:

$$\left(P_R - P_{TR}\right) = \frac{P_4}{e_4} + \frac{P_s}{e_s} + \frac{P_r}{e_r} + \frac{P_c}{e_c} \tag{5}$$

Solution for P_c and substitution of numerical values yields

$$P_c = \frac{P_R - 0.6}{1.25} - 12.9 \text{ watts} \tag{6}$$

Substituting $P_c = P_{TB}$ (which is to say that all loads at the battery voltage level are supplied by the battery only), $P_R = 17.5$ watts; this is the minimum RTE output power required to sustain any operation whatever with the system configuration of Figure 2-3. If P_R should go below 17.5 watts, there will be insufficient power available to deliver to loads at other regulated buses (i.e., +4, -6.3, -12, and +24-volt converter outputs) during Operate.

Energy Balance at Battery Voltage Level; Operate Time Relationship To RTE Output Capability

It has been shown that, because of the particular nature of the over-all load profile, it takes at least 4.9 watts RTE output to sustain operation during the Charge mode and 17.5 watts during the Operate mode. Thus, a 4.9-watt RTE is of academic

interest only; battery charge with such an output is always zero. It can be compared to the 6.06-watt solar array required to just support all loads during Charge. The relatively low, constant load level required in Charge increases to another, higher level during Operate, with a new minimum requirement of $P_R = 17.5$ watts. Given this output, charger output is zero during Operate. Assuming that the RTE output is constant regardless of whether the mode is Charge or Operate, 17.5 watts output will charge the battery during the Charge mode and the system will thus be able to sustain some Operate time; this is about 6 hours per 24 hours, as is subsequently shown. It is clear that only RTE outputs of 17.5 watts or greater are relevant and the energy balance calculations will be based on that fact. This is a constraint imposed only by the power subsystem configuration of Fig. 3, where the battery is placed at roughly a +25-volt level (at which level peak loads and other major load variations are required in this system). This assures a power subsystem which is probably most efficient and lightest in weight, as long as the Operate duty cycle required is not less than 6 hours per earth day.

The over-all integrated power profile (Figure 11) suggests that the fraction of Operate time during which the battery is in discharge depends on the magnitude of the charger power output P_c.

<u>Case 1.</u> $\qquad 9.35 \leq \left(P_c - P_{TB}\right) \leq 24.35$

Referring to Fig. 11, the energy balance equation at battery voltage level for this case is:

$$\left(P_c' - P_{TB}\right)e_B \left(24-T\right) = \frac{T}{72.54} \left[7.5(30.6 - P_c + P_{TB}) + 41.14(24.35 - P_c + P_{TB})\right]$$

$$\tag{7}$$

$$- \frac{Te_B}{72.54} \left[11.8(P_c - P_{TB} - 9.35) + 12.1(P_c - P_{TB} - 4.35)\right]$$

Substituting for P_c' and P_c (equations 2 and 6), then substituting numerical values and solving for T,

$$T = 75 \frac{P_R - 4.9}{163 - P_R} \ hours \tag{8}$$

From equation (6) it is determined that equation (8) is valid over P_R limits of

$$29.2 \leq P_R \leq 48$$

Substitution of $T = 24$ hours into equation (8) yields $P_R = 43.3$ watts, which is the largest useable RTE output for this system with the power requirements as given. It should be noted that, practically speaking, the maximum operate time of 24 hours per earth day limits P_R to 43.3 rather than mathematically by $P_R = 48$.

Case 2.

$$4.35 \leq (P_c - P_{TB}) \leq 9.35$$

A new energy balance equation, properly solved, yields

$$T = 61.3 \frac{P_R - 4.9}{139 - P_R} \text{ hours,} \tag{9}$$

for

$$22.95 \leq P_R \leq 29.2$$

Case 3.

$$0 \leq (P_c - P_{TB}) \leq 4.35$$

$$T = 51.2 \frac{P_R - 4.9}{119 - P_R} \text{ hours} \tag{10}$$

for

$$17.5 \leq P_R \leq 22.95$$

Substituting $P_R = 17.5$ watts into equation (10), $T = 6.35$ hours, which is the minimum Operate time duty cycle with a system as shown in Figure 3.

Equations (8), (9), and (10) are plotted in Fig. 4. The resulting plot appears to be nearly a straight line, suggesting that the power profile for this mission has little effect on the Operate time variation.

Battery Discharge, Ampere-Hours per Hour in Operate (q)

In the right-hand member of equation (7), the first expression in major brackets represents watt-hours battery discharge. Setting $T = \Delta T =$ one hour, assuming a battery discharge voltage of 25 volts average (24 Ag-Cd cells @ 1.05 volts), and substituting both conditions into the referenced expression.

$$q = \frac{7.5(31.2 - P_c) + 41.14(24.95 - P_c)}{72.54 (25)} \text{ ahrs per hour of operate time} \tag{11}$$

Substituting for P_c (equation 6) and simplifying,

$$q = 1.053 - 0.02145\, P_R \, , \tag{12}$$

for
$$29.2 \leq P_R \leq 48$$

Similarly, for $22.95 \leq P_R \leq 29.2$,

$$q = 1.205 - 0.02665\, P_R \tag{13}$$

and, for $17.5 \leq P_R \leq 22.95$,

$$q = 1.305 - 0.0319\, P_R \tag{14}$$

Quantity "q" represents net amp-hours battery discharge per hour of operate time, assuming that all battery discharge during that hour occurs without any in-between recharge. This is conservatively applied to both the RTE and the solar array subsystem analysis published in the SLRV Phase I Final Report.

Using the plot of Figure 4, P_R of equations (12), (13), and (14) is related to Operate time, enabling a plot to be made of battery discharge vs. total Operate time per earth day. Such a plot has been made and is indicated in Figure 5, except that 2q vs. T is plotted to show the total required battery capacity if discharged to 50 percent maximum depth. (See the notes at the bottom of Figure 5.)

Battery Charge Current

Battery charge current I_{ch} can be expressed as

$$I_{ch} = \frac{P_c' - P_{TB}}{V_{ch}} \tag{15}$$

Substituting for P_c' from equation (2), and appropriate numerical quantities, and simplifying,

$$I_{ch} = \frac{P_R - 4.9}{45.6} \text{ amperes} \tag{16}$$

P_R is related to T in Figure 4 and battery charge current vs. total Operate time per earth day is plotted in Figure 5.

V.2-6 Definition of the Symbols

Symbol	Value or Defining Equation	Definition
e_4'	0.65	+4-volt switching regulator efficiency factor when in Charge mode
e_4	0.85	same, when in Operate mode
e_s	0.70	-6.3 and -12-volt converter output path efficiency factor
e_r	0.82	+24-volt converter output path efficiency factor
e_{24}	0.85	+24-volt switching regulator efficiency factor
P_4'	1.10 W	+4-volt load power in charge
P_4	7.5 to 7.9 W; assume 7.5 W weighted average.	+4-volt load power in Operate mode
P_s'	0.234 W	-6.3 and -12-volt combined converter output to load when in Charge mode
P_s	4.04 W	Same, when in Operate mode
P_c'	Eq (2)	Charger output in Charge mode
P_c	Eq (6)	Same, when in Operate mode
e_c	0.80	Charger output path efficiency factor
P_R	Eq. (1) and (5)	RTE Power Output (raw)
P_{24}	Related to Figures 2-7 and 2-8	+24-volt switching regulator output
e_B	0.68	Ag-Cd watt-hour charge-discharge efficiency factor; Amp-hr efficiency factor = 0.95; discharge-to-charge voltage ratio = 1.08 (average) to 1.50 ((average)

Symbol	Value or Defining Equation	Definition
P_r	1.25 W	+24-volt converter output power
P_{TB}	0.6 W	Telemetry circuits loss at battery voltage level (20 ma at 30 volts average)
P_{TR}	0.6 W (assumed)	Telemetry circuits loss at RTE output voltage level
I_{ch}	Eq. (16)	Battery charge current
V_{ch}	36.5 volts	24-cell Ag-Cd battery charge voltage
P_B	Eq. (4)	Battery charge power
a	Fig. 2-6	RTE watts per pound (converter not included)
T	Eq. (8) to (10)	Operate time duty cycle, hrs per earth day
ΔT	Fig. 5	Hrs Operate time per cycle
q	Eq. (12) to (14)	Amp-hrs battery discharge per hour when in Operate mode
W		Total RTE power supply subsystem weight, pounds
C	Fig. 5	Amp-hrs total on-board battery capacity.